

Real-Time Simulation of Multi-Hop Ad hoc Networks

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1 Introduction

An ad hoc network comprises a collection of mobile hosts such as laptops with wireless radio interfaces dynamically to a temporary network. Due to the limited transmission range of these interfaces, multiple network hops may be needed for two hosts to communicate with each other. Numerous new and innovative developments particularly in the telecommunication and (mobile) network sector call for new or extended network simulators. In this work we want to emphasize the range of use and elaborate on the development of a tool for simulating network delay and loss characteristics in real-time for multi-hop ad hoc networks (MANETs) [Per01].

A real-time network delay and loss simulator (RDLS) is understood as a system providing network interfaces where other systems can connect to. These systems can host distributed applications communicating over the RDLS without noticing any differences between the simulator and a physical network. The main issue of a RDLS is to compute the effects of the path of packets through a simulated switching network, which results in delays or losses. Also it has to deliver each packet - if not decided to be lost - with the computed delay accurately. The simulated network may include network-internal sources of background load as well as interfaces for external sources of load (e.g. real or modeled applications, possibly combined with artificial load generators, etc).

With an RDLS two main tasks can be addressed without building up a complete physical network: On the one hand the behaviour of a distributed application can be evaluated assuming different network configurations (e.g. different levels of load, more or less loss-affected links, etc). On the other hand the behavior of the network can be evaluated with changes made on the application side (e.g. load dependant application-layer encoding). Examples for commonly used distributed real-time applications are video conferencing systems or voice over IP.

Main requirements an RDLS has to fulfill are

- accurate end-to-end computation of
 - delays: The delays computed by the simulator should be sufficiently close to the expected delays resulting from physical components.
 - losses: The situations in which packets have to be dropped should closely match situations where losses occur in real systems.

- exact fulfillment: Exactly the packets which have been computed to be dropped should be dropped, the remaining packets have to be delivered according to the time calculated by the simulator.

An RDLS addressing the functionality needed for conventional packet switching networks has been developed and presented to the public by our group, cf. [Sch00, Böh00, BS00]. This simulator is described in the following section. In order to handle mobile switches as well, the existing system has to be extended and as well delay as loss computation have to be modified. It should be noted here that especially in the context of multimedia communication, a field that has experienced a rapid growth over the past few years, a mobile network with its inherent smaller bandwidth and higher error rate, may be the bottleneck of any data exchange [JKK00]. Therefore it is necessary to provide a tool with capability to simulate the delay and loss characteristics of MANETs.

Remark: With an RDLS available that support one or more different types of networks, in this context called transit networks, a RDLS of switched networks with transit networks as individual subsystems interconnected to fixed gateways should easily be implemented. In case of a switched network the delay for each packet sums up from the delays calculated for each transit network plus the delays implied through the gateways between them. Analogously a packet is dropped during the end-to-end transmission if any transit network drops it.

For developing a RDLS for handling several different network types, in this paper especially for handling MANETs, a main task is to find out how delays and losses are influenced and how to compute them. Packet delays and losses are caused especially as a consequence of

- network load, in particular
 - traffic matrix (source-destination pairs, traffic intensities)
 - load inserted by the node hosting the source part of the distributed application
 - lengths and other attributes (e.g. priorities) of data units
- node mobility, in particular mobility of
 - the nodes hosting source and destination parts of the distributed application
 - the switching nodes
- routing decisions
- resources available at the switches, in particular
 - cpu / switching capacity
 - internal buffer capacity
- quality of radio links, influenced, e.g., by
 - geographical distances between hops

- obstacles
- interferences
- media access control
- usage of error correction protocols

Regarding these (and more) attributes a suitable model including sufficient details to allow some valid prediction of delays and losses has to be found. Nevertheless simplicity is a major premise so that the computations can be done in real-time though the simulator shall run on a single PC/workstation or be distributed on just a few machines. But this implies inaccuracy, hence a tradeoff between simplicity and the required level of accuracy has to be chosen.

In the following section our existing simulator with capability to simulate delays and loss characteristics in networks using fixed routing will be described now. After that, possible proposals for extensions to handle MANETs will be discussed.

2 An existing network simulator

During the last years a real-time network simulator has been developed in our group. The simulator calculates delays and losses for individual packets being routed through a path of switching nodes. In one variant each switching node is modeled as a queuing system consisting of a waiting queue, a scheduler and a time interval for the service itself. The routing through the network is fixed, given by the model. Beside the possibility to inject load from real sources the simulator is able to add a load artificially generated – several types of distributions for the intervals between consecutive packets have already been developed.

The main aim while developing the network simulator was to allow a bunch of possibilities to evaluate the interactions between networks and the load injected. This simulator – based on events – has characteristics, which differentiate this simulator from others as [BEF00] and can be summarized as follows:

- Ensure real-time capabilities: The combination of load generated by applications with artificial load enforces real-time capabilities for the complete simulation system
- Flexibility regarding the way to calculate losses and delays: Analytical models, discrete-event simulation on the basis of queueing networks and the usage of traces have already been implemented and tested for models of standard packet switching networks (such as **Comment:** hmm). It is planned to extend these solutions towards a broader basis.
- Combination of real load with a load generated artificially: Any load can be combined to shape the total load that affects the behavior of the simulated network.
- Flexibility regarding the external interfaces: The simulator is not restricted to single protocols or interfaces but a flexible architecture enables straight-forward extensions.

- Flexibility regarding the surroundings: As few assumptions as possible concerning the environment, e.g. hardware, operating system, network connections, etc. are made for both the architecture and the implementation.

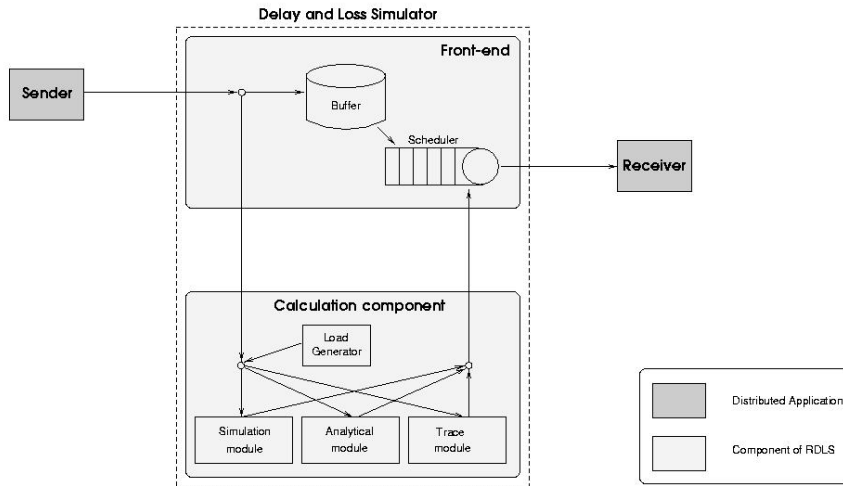


Figure 1: RDLS system architecture and its embedding into a distributed application

The simulator is built in modules and can be exchanged and adopted quite easily. It is distributed to enable load sharing on multiple processors. The coarse architecture of the simulation system is shown in figure 1. It consists of a front-end and a computing module. The front-end provides interfaces for external traffic and buffers for incoming packets – after taking a timestamp for each packet – until delivery or deletion based on the calculated result for a packet. The calculation component computes the time of delivery for each packet, or decides that the packet should be lost.

A broad test series showed that the implemented simulator is able to fulfill all the requirements as stated above and so it should be extendable especially for MANETs.

3 Extension of our existing network simulator to MANETS

3.1 Main Tasks

In the previous sections we pointed out the requirements we attach importance to. Hence the following tasks result, which have to be addressed to enable the simulation of MANETS:

- Suitable routing representation of inner nodes and their mobility behavior.

- Extended routing and delay computation. Compared to the model of the previously described real-time simulator, both the number of hops and the geographical distances between source and destination host may vary.
- How can the hop-to-hop loss probability be modeled?

3.2 Suggested Solutions

The network simulator presented before has been constructed in a way to ensure an uncomplicated extension of the features supported. We suggest to allow a detailed modeling, though, for reduction of complexity a less detailed model can be generated too, what enables an analysis of the effects caused by a reduction of details. Several issues mentioned in the section before have to be addressed as part of a detailed MANET model, including especially these:

- A two-dimensional room with the nodes moving within the room is modeled.
- Appropriate routing algorithms [BMJ⁺98, RT99] have to be implemented due to the movement of the nodes. This implies that a new type of events to handle changes in the routing has to be added into the simulation environment. A variety of solutions would be possible:
 - Adaptive routing vs. fixed routing for artificial background traffic.
 - Pure simulation vs. partly analytical calculation, i.e. for calculating the waiting times on a statistical basis. This would simplify the calculation of the delays significantly.
 - Usage of different routing algorithms. These algorithms may be build either on the basis of a global view of the complete network or on the basis of the local view of single nodes.
- The computation of delays and losses is assumed to be mainly dependent of the routing, the number of hops and the load within the nodes.
- Other events with a major influence to transmission characteristics, as obstacles may be considered later.

Alternatively, the MANET could even be modeled as a black box. In this case the single processes within the net are not represented, but the overall end-to-end delay and loss behavior is modeled (analytically) or determined by using a trace. Due to the strong abstraction the difficulty is to find a sufficiently valid an representative model or trace – if existing.

The most important decision to be made in order to determine an appropriate solution are:

- Possibility to exchange performance information between the network and the distributed application. The more information is exchanged in order to assist an application to adapt to different traffic situations the more detailed the model has to be.
- Complexity of overall MANET model: The more complex the considered system is, the more the model of it has to be simplified in order to handle the computation under real-time conditions.

- Kind of mobility to be modeled: The more quickly and often the position of nodes are changed, the more important the location of nodes are for the calculation of the routes and the more often the routes have to be recalculated.

3.3 Expected results

The suggested solution builds strictly on the real-time network simulator already existing, so the accuracy of the results should be quite similar to that of the existing implementation, leading to deviations well below 1 ms. Due to the possible range of solutions presented the evaluation of a model can be supported by reducing the complexity of the model on the one hand. On the other hand the more detailed the models used are, the more exact these models can be. Obviously there is no optimal solution for all kind of problems, so the simulator has to be constructed as flexible as possible. Further research has to prove the ability to simulate the behavior of MANETs in real-time, and has to provide insight into the limits under given conditions (e.g. size of network, number of users, etc).

4 Conclusion

In this workout we motivated the development of a tool for simulating network delay and loss characteristics in real-time and its extension to multi-hop ad hoc networks. Regarding the desired range of applications, which we presume for such a tool, we derived a set of requirements to be taken into account. Since the simulator built by our group in the past is already able to handle connections between two end-systems based on static links successfully, we decided to expand this existing system to handle MANETs. Therefore, we described the existing system and discussed several potential approaches to integrate MANETs.

Exhaustive experiments with the existing real-time simulator and their comparison to physical networks show that this system is a powerful tool for evaluating the behavior of a wide range of protocols and distributed applications communicating via different network configurations. In order to keep step with current trends in networking we consider the extension of this tool to handle mobile multi-hop ad hoc networks as a promising R&D activity.

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